Introduction: Super-sensing through industrial process tomography

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1. Process monitoring and super-sensing

Super-sensing by means of industrial process tomography tools allows seeing inside of process [3],[6]. This is done through non-invasive and non-intrusive measurement that are spatial and temporal aware with the aid of intelligence of analysis methods forming the theory of tomographic imaging. There have been exciting developments in this area in past few years, which led to many new commercial opportunities. Further development will make these technologies widely used in more and more manufacturing processes leading to cost effective, energy efficient and more importantly more sustainable processes. It is well understood that a new scientific direction is needed to capitalise on past progress and look for future. Industrial process tomography now could be better understood by the concept of super-sensing. The terminology of super-sensing in this special issue is a first step to bring various disciplines in this field together by means of multi-dimensional sensing and analysis.

2. Tomographic Imaging

Tomography is a technique that creates a cross sectional or volumetric image of internal physical properties of an object. Tomography is imaging the body or object by exposing it to form a penetrating wave. There are three main elements to the tomography, source of wave, detectors to absorb wave and image construction algorithm. The emitted and received wave varies depending on the medium it is exposed to; the variation on signal is used to construct an image. The two main categories are "hard field tomography" and "soft field tomography" (figure 1). There are several examples for each of this tomography type. Hard field tomography examples are X-ray tomography, ultrasound tomography, Hydraulic tomography (HT), and Gamma ray tomography, and MRI. Soft field tomography includes Electrical impedance tomography (EIT), Electrical capacitance tomography (ECT), Magnetic induction tomography (MIT), and optical tomography. The hard filed tomography has different characteristics to soft field tomography. They are different in a way that, for hard field tomography, such as X-ray, the path of the transmitting signal is in a straight line pattern, and the only factor that can affect the signal strength is the material along that path, regardless the position of the material. Where the soft field tomography, such as MIT, EIT there are other factors that can influence the transmitting signal, like the distribution of electrical parameters (conductivity and permeability) inside and outside the measuring region and specially lines between source and detector [1]. This presents a great difficulty when computing the image reconstruction algorithm for soft field tomography. At the same time there are extensive similarities in fundamental of the mathematics of the imaging in both hard field and soft field tomography [4],[5].

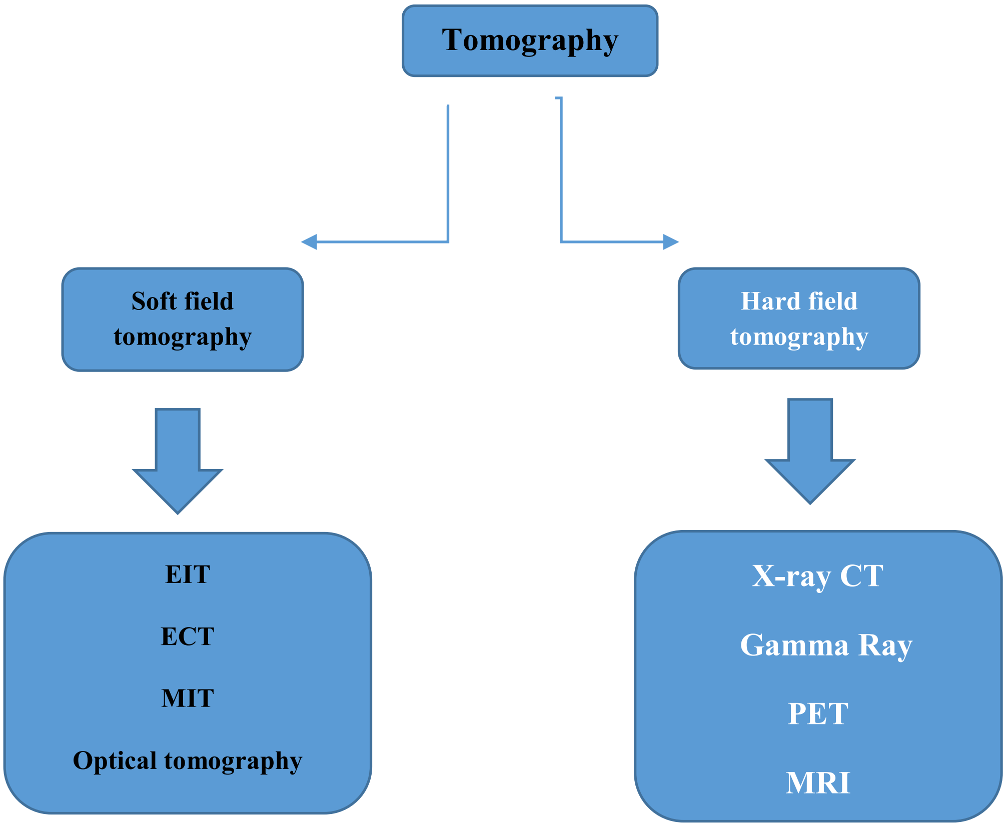


Figure 1: Classification of tomography

Both soft field and hard field tomography are part of the industrial process tomography methods. Table 1 [2] summarizes a number of existing tomography techniques with their characteristics and suitable applications.

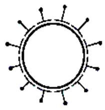
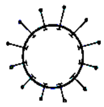
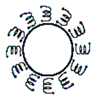
Table 1: Types of different tomography techniques [2][3].

	Tomography Technique	Characteristics	Applications
EM (Hard field)	γ-ray	Radio-active sources Fast scanning speed Potentially fast	Industrial applications
	X-ray	High resolution Mechanically scanned Radiation confinement	Medical imaging Industrial applications
	UV Optical Infrared	Fast Optical access	Micro-structural Medical monitoring
	Millimeter Wave	System component Emerging	Air traffic monitoring
EM (Soft field)	Microwave	Fast Moderate resolution (Wavelength dependent)	Thermal mapping of reactors
	Capacitance (ECT)	Low resolution	Passive electric properties mapping
	Impedance (EIT)	Fast	
	Inductance (MIT)	Robust	
		Low cost	
Nuclear Particle	Positron Emission	Uses labeled particles Similar to CT reconstruction algorithm	Medical imaging
	Neutron	High resolution Pulse or radioactive source Radiation confinement	Micro-structural monitoring (Medical)
Others	Nuclear Magnetic Resonance		Micro-structural monitoring (Medical)
	Ultrasound	High Resolution Phase array for beam steering	Medical imaging Industrial monitoring
	Thermal Conduction (Heat Flux)	Slow Soft field	

2.1 Electrical tomography

The electrical tomography uses electrical properties of the medium to construct an image. The conductivity, electric and magnetic field varies depending on medium. The system has fast response and it is relatively inexpensive compared to the other methods such as X-rays also it is not harmful. The downside of the electrical tomography is its low resolution and complicated image construction algorithm. The electrical tomography is has numerous applications such as geology to investigate rocks, industrial process such as investigating wear on pipelines, and fluid flow. The different sensing techniques for electrical tomography are presented on table 2.

Table 2: Electrical Tomography techniques [2]

Method	Sensor elements	Typical arrangement	Measure values	Typical material properties ??	Typical material
ECT	Capacitive plates		Capacitance **C**	ε_r 1 – 100 σ < 10^{-1} S/m (low)	Oil, water, non-metallic powders, polymers, burning gasses
ERT (EIT)	Electrodes		Resistance (Impedance) **R / Z**	σ 10^{-1} - 10^{7} S/m (wide) ε_r 10^{0} - 10^{2}	Water / saline, biological tissue, rock /geological materials, semi-conductors e.g. silicon
EMT (MIT)	Coils		Self/ mutual Inductance **L / M**	σ 10^{2} - 10^{7} S/m (high) μ_r 1 to 10,000	Metals, some minerals, magnetic materials and ionised water ?

As an example, EIT is a tomographic imaging system; device is capable of providing high temporal resolution with low spatial resolution. The system operates by injecting constant current between two pairs of electrodes and measuring the potential difference on the remaining electrodes. The potential difference is dependent upon the conductivity of the object. Figure 2 shows the EIT diagram. The hardware consists of electrodes, data acquisition and software to create images; a test phantom (figure 2 right) is often used to verify EIT imaging. Figure 3 shows an EIT image of electrical conductivity variation due to presence of a plastic bottle in conductive saline background. After verifying a process tomography system in a lab based phantom studies, the systems go through field studies through real industrial process monitoring [3].

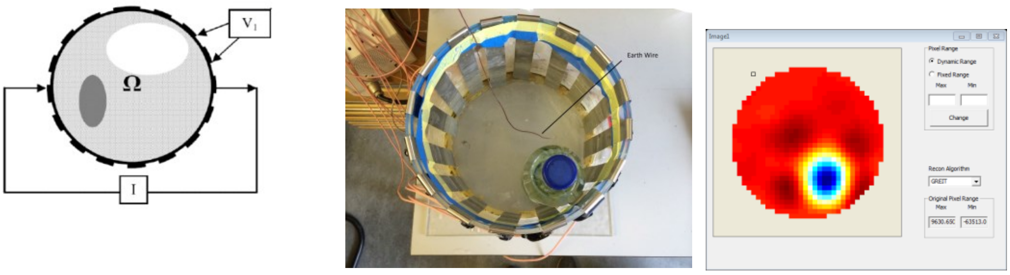


Figure 2: An EIT measurement principle (V1) is measured after current (I) has been injected. Typically phantoms are used for proof of principle and reconstructed images

3. Conclusion:

The super-sensing measurements are techniques that are providing spatially and temporally aware information about inside of industrial processes. The field of research is in a transition period of going from a tool for R&D engineers to a monitoring tool for production line. The research in the field has grown very fast in past few years mainly due to higher computer power, which allowed multidimensional imaging to be done in near real time. The commercial companies are nearing to develop real time 3D imaging, which was unthinkable a decade ago. Superior algorithm and computational enhancement played a key role in bringing this field to the point that it lead to successful commercial development. This special issue highlight some of recent progresses and open up a new frontier.

References:

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